Enhancing6G Communication with Full Duplex and Duplexing Aware Cellular Access

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ABSTRACT:

The implementation of a Massive MIMO-based 6G communication system with Full Duplex (FD) and Duplexing Aware Cellular Access (DACA) aims to enhance spectral efficiency and network capacity while addressing self-interference challenges. The project is executedintwophases:first,implementingFDwithand without Self Interference Cancellation (SIC) and Reconfigurable Intelligent Surfaces (RIS); second, integrating DACA with SIC and RIS for improved resource allocation and interference management. SIC techniques,includingdigitalandanalogcancellation,are employed to enhance system performance. Key metrics such as Signal-to-Noise Ratio (SNR), Bit Error Rate (BER), Mean Square Error (MSE), and data rates are analyzed using MATLAB to compare FD with SIC and RIS against DACA with SIC and RIS. The results demonstratethattheDACA-basedsystemofferssuperior efficiency,lowerlatency,andbetterresourceutilization, making it a strong candidate for next-generation 6G networks.

Keywords: 6G Communication, Full Duplex (FD), Duplexing Aware Cellular Access (DACA), Self-Interference Cancellation (SIC), Reconfigurable Intelligent Surfaces (RIS), Massive MIMO, Signal-to-Noise Ratio(SNR), Bit Error Rate(BER), Mean Square Error(MSE),ThroughputOptimization,Terahertz(THz) Communication, mm Wave Technology, Spectral Efficiency, Zero Forcing (ZF) Method, MATLAB Simulation.

I. INTRODUCTION:

Overview of MIMO in 6G :Wireless communication systemsareevolvingrapidlytomeettheever-increasing demand for higher data rates, lower latency, and improved spectral efficiency. Current wireless technologies rely on multiple-input multiple-output (MIMO) systems, orthogonal frequency division multiplexing (OFDM), and frequency-division or time-divisionduplexingtechniques.However,these conventional methods still face limitations in maximizing resource utilization.

Importance: MIMO technology optimizes spectral efficiency, increases data throughput, and enhances network resilience. Its ability to support ultra-reliable low-latencycommunication(URLLC)makesitessential for applications such as autonomous systems, remote healthcare, and smart infrastructure. Furthermore, advancements in MIMO contribute to sustainable wireless networks by improving power efficiency and mitigating interference

Half-Duplex (HD) systems, which operate by either transmitting or receiving signals at a given time, suffer from spectral inefficiency as only one communication direction is active at a time. To overcome these inefficiencies, Full-Duplex (FD) communication has emerged as a promising technology that enables simultaneous transmission and reception on the same frequency band, theoretically doubling spectral efficiency. However, FD systems introduce self-interference(SI),whichmustbeeffectivelymitigatedfor practical implementation.

Duplexing Aware Cellular Access (DACA) has been introduced as an enhancement to FD systems, allowing dynamic allocation of resources based on the device's ability to operate in FD or HD mode. By intelligently managing duplexing modes, DACA ensures optimal spectrum utilization and reduces interference-related performance degradation.

Motivation: The motivation behind this study lies in addressing the limitations of conventional HD systems while optimizing FD technology for practical deploymentin6Gnetworks.WhileFDofferssignificant improvements in spectral efficiency, overcoming self-interference remains a major challenge. Implementing advancedself-interferencecancellation(SIC)techniques and integrating Reconfigurable Intelligent Surfaces (RIS) can significantly enhance FD performance. Furthermore,DACAcanensureefficientresource allocation, leading to improved overall system performance. This research aims to demonstrate the benefits ofintegratingDACAwith FDandSICin next-generation wireless networks.

Research: Recent studieshighlight FD communication as a key enabler for 6G. While FD improves spectral efficiency, self-interference poses a significant challenge. SIC techniques, including passive suppressionandactivecancellation(analoganddigital), have been explored to mitigate interference. The introduction of RIS has further enhanced signal propagation, making it a critical component in next-generationwirelessnetworks.Existingresearchsuggests that DACA can optimize network performance by intelligently managing user duplexing modes

II. FUNDAMENTALSOF6GMIMO:

Massive MIMO: Utilization of large-scale antenna arrays to improve spectral efficiency and network performance through spatial multiplexing.

Reconfigurable Intelligent Surfaces (RIS): Metasurfaces capable of dynamically modifying electromagnetic waves to optimize signal propagation and reduce interference.

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AI-drivenMIMO:Leveragingartificialintelligencefor adaptive beamforming, interference cancellation, and real-time network optimization.

III. CHALLENGES&SOLUTIONS:

Half-Duplex Communication and Its Limitations: Half-Duplex (HD) communication, the traditional approach in wireless networks, allows devices to either transmit or receive signals at a given time but not simultaneously. The two primary types of HD communication are: Time Division and Frequency Division Duplexing.

Full-Duplex Communication and Its Challenges: Full-Duplex (FD)communication aimstoovercomethe inefficiencies of HD by allowing simultaneous transmission and reception of signals on the same frequency band. This results in significantly higher spectral efficiency and reduced latency. However, the primary challenge in FD systems is self-interference (SI), where a device's transmitted signal interferes with itsreceivedsignal,significantlydegradingperformance.

ToaddressSI, advanced cancellation techniques such as passivesuppressionandactivecancellationmethodshave beendeveloped.Passivesuppressiontechniques,suchas antenna separation and polarization, help reduce interference at the hardware level. Active cancellation techniquesincludeanalogcancellation,whicheliminates SI before the signal reaches the receiver, and digital cancellation,whichfurtherprocessesthesignaltoremove residual interference. However, hardware imperfections such as phase noise, power amplifier nonlinearity, and frequency response distortions introduce additional challenges, requiring complex signal processing techniques to ensure effective FD operation.

The Role of Duplexing Aware Cellular Access (DACA): WhileFDimprovesspectralefficiency,itdoes not guarantee optimal performance for all users due to hardwarelimitationsandvaryinginterferenceconditions. Duplexing Aware Cellular Access (DACA) addresses this issue by dynamically allocating resources based on each user’s duplexing mode, whether Full-Duplex or Half-Duplex.DACA ensures efficient spectrum utilization by allowing devices that can operate in FD mode to leverage its benefits while assigning HD operation to users with severe interference constraints. Thishybrid approach maximizesnetwork efficiencyand minimizestheimpactofresidualSI.Additionally,DACA enhances resource allocation, reducing latency and improving overall system throughput compared to traditional FD-based systems.

IV. DESIGNMETHODOLOGY:

The design methodology for implementing a 6G communication system with Full-Duplex (FD) and Duplexing Aware Cellular Access (DACA) involves severalcriticalsteps.Thefirststepfocusesondeveloping a robust system architecture that integrates FD technologywithSelf-InterferenceCancellation(SIC)and Reconfigurable Intelligent Surfaces (RIS). Massive MIMO technology is incorporated to improve signal propagation,allowingefficientresourceallocationacross multiple users.

Self-Interference Cancellation (SIC)isa keycomponent in the design, employing both passive and active suppressiontechniques.Passivemethodssuchasantenna separation and polarization are used to minimize interference at the hardware level. Active cancellation techniques, includinganalog and digital SICalgorithms, are applied to further reduce residual interference, ensuringacleanerreceivedsignal. Theintegrationof6G technologies, such as Terahertz (THz) and millimetres-wave (mm Wave) communication, enables ultra-high-speed data transfer with reduced latency. The incorporation of Reconfigurable Intelligent Surfaces (RIS) enhances signal propagation by dynamically controlling the reflection and scattering of wireless signals, leading to improved coverage and spectral efficiency.

To validate system performance, MATLAB simulations are conducted to analyse key performance metrics, including Signal-to-Noise Ratio (SNR), Bit Error Rate (BER), Mean SquareError (MSE), and throughput.The results from these simulations provide insights into the effectiveness of FD with SIC and RIS compared to traditional HD and standalone FD systems, demonstratingtheadvantagesofimplementingDACAin next-generation 6G networks.

V.TOOLSUSED:

To implement and analyze the proposed 6G communication system, various software tools and toolboxes are utilized:

MATLAB Software: MATLAB is used as the primary simulation platform due to its powerful computational capabilities. It provides a flexible environment for simulating full-duplex systems and enables high-speed matrix operations, algorithm testing, and performance evaluation. MATLAB also supports extensive data visualization, making it easier to analyze results effectively.

CommunicationSystemsToolbox: Thistoolbox offers built-infunctionsforsimulatingwirelesscommunication systems. It facilitates the design and analysis of MIMO and full-duplex communication setups, simplifying the modelling of interference and signal propagation in 6G scenarios. The toolbox plays a crucial role in evaluating system performance under different communication conditions.

Signal Processing Toolbox: The Signal Processing Toolbox provides advanced tools for analyzing and improving signal quality. It assists in designing interference suppression filters for full-duplex systems and enables real-time simulation of signal processing algorithms.Thetoolbox isinstrumentalin implementing self-interference cancellation techniques, such asanalog and digital cancellation methods.

VI. APPLICATIONS:

6G MIMO technologysupports various groundbreaking applications:

AI-driven Beamforming: Machine learning algorithms optimize beamforming strategies to enhance network performance.

Unmanned Aerial Vehicles (UAV) Communications: High-speed, low-latency connectivity enhances UAV applications in surveillance, delivery, and disaster response.

Satellite and Non-Terrestrial Networks: 6G MIMO ensuresseamlessconnectivitybetweenterrestrialand space-based communication systems, improving global coverage.

Holographic Communication: Advanced MIMO techniques support real-time holographic video streaming for immersive telepresence applications.

VII. BLOCKDIAGRAM:

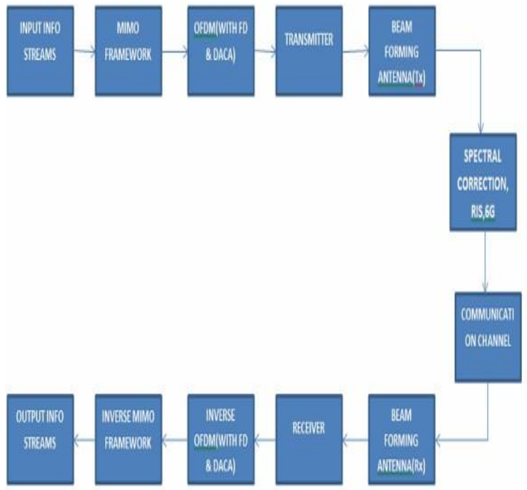

Fig-1:SchematicBlockoverviewoftheProposedSystem.

Full Duplex (FD): Full Duplex allows a device to transmitandreceivesignalsatthesametimeonthesame frequency.Itdoublesthespectrumefficiency,improving data rates.

DuplexingAwareCellularAccess(DACA):Asystem that optimizes how users access the network based on their duplexing mode (Full Duplex or Half Duplex – Half Duplex). Not all users can efficiently operate in Full Duplex mode due to hardware limitations. Duplexing AwareCellularAccesshelpsscheduleusersefficientlyto maximize network performance.

Self-Interference Cancellation (SIC): In full-duplex communication the transmitted signal can interfere with thereceived signal. Self-Interference Cancellation helps removethisinterferencesothatthereceivercancorrectly detect the desired signal.

ReconfigurableIntelligent Surface(RIS):Asmart surface made up of manytinyantennas or reflectors that control and improve wireless signals by reflecting them in desired directions. This enhances signal strength and coverage, making communication more efficient.

Signal to Noise ratio (SNR): Signal to noise ratio measures the how strong a signal is compared to background noise in a communication system.

Bit Error Rate (BER): Bit Error Rate measures the percentage of bits received incorrectly compared to the total bits transmitted. It tells you how many bits got flipped or lost during transmission.

Mean Square Error (MSE): Mean Square Error calculatestheaverageofthesquareddifferencesbetween the original transmitted signal andthereceived signal. It shows how much the received signal deviates from the original.

MinimumMeanSquareError(MMSE):MinimumMean SquareError isthesmallest possibleerrorafterapplying an optimal filter to minimize noise and interference.

Throughput: Throughput measures the successful data transmission rate, meaning how much useful data is transmitted per second, considering errors.

VIII. RESULTS:

Biterrorrate:

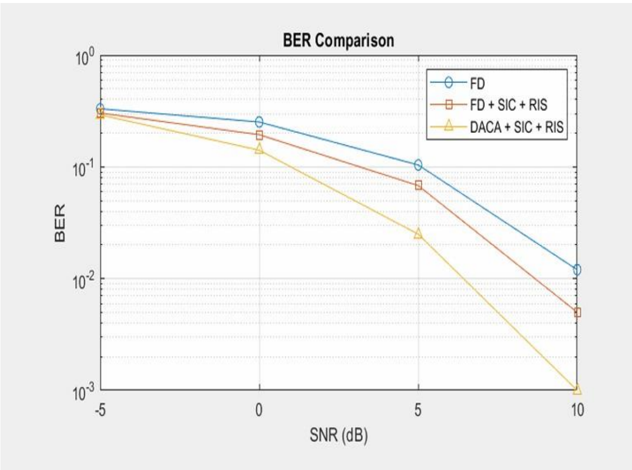

Fig-2:BERGraph

TheBERperformanceofthethreesystem configurations is illustrated in Figure 2. The baseline Full-Duplex (FD) system exhibits the highest BER, indicating the challengesposedbyself-interference.IncorporatingSelf-Interference Cancellation (SIC) and Reconfigurable Intelligent Surfaces (RIS) in the FD + SIC + RIS configuration significantly reduces the BER, demonstrating the effectiveness of these techniques in improvingsignalquality.However,theDuplexingAware Cellular Access (DACA) system, when combined with SIC and RIS (DACA+ SIC + RIS), achieves the lowest BER across all SNR values. This superior performance can be attributed to the DACA system's ability to dynamically optimize resource allocation and minimize interference by intelligently scheduling users in full-duplex or half-duplex modes. The steeper slope of the DACA+SIC+RISline,asSNRincreases,indicatesa more rapidimprovementinBER,furtherhighlightingitsefficiency in high-SNR regimes.

FORMULA:

BER=sum(bits~=(received_bits>0.5))/N

BERComparision:

SNR(dB)	FD(BER)	FD+SIC+RIS (BER)	DACA+SIC+RIS(BER)
-5	0.3	0.25	0.22
0	0.15	0.12	0.1
5	0.05	0.03	0.015
10	0.015	0.008	0.001

Meansquareerror:

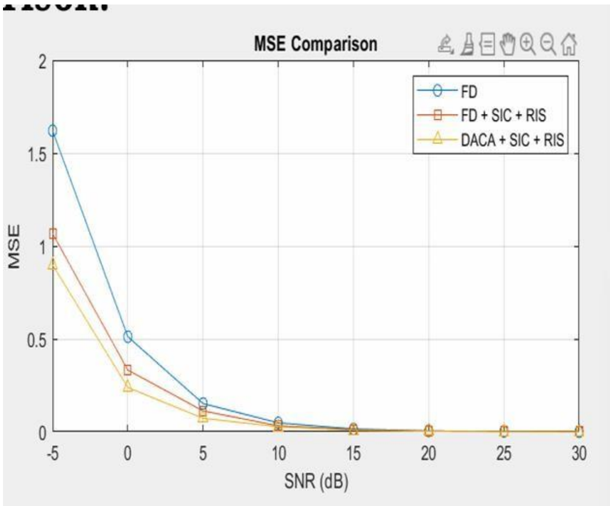

Fig-3:MSEGraph

TheMSEperformanceofthethreesystemconfigurations is presented in Figure 3. The baseline Full-Duplex (FD) system exhibits the highest MSE, particularly at lower SNR values, highlightingthe impact of self-interference on signal distortion. Incorporating Self-Interference Cancellation (SIC) and Reconfigurable Intelligent Surfaces (RIS) in the FD + SIC + RIS configuration significantly reduces the MSE, demonstrating the effectiveness of these techniques in improving signal fidelity.However,theDuplexingAwareCellularAccess (DACA) system, when combined with SIC and RIS (DACA + SIC + RIS), achieves the lowest MSE across all SNR values. This superior performance can be attributed to the DACA system's ability to dynamically optimize resource allocation and minimize interference. As the SNR increases, the MSE for all three configurations converges towards zero, indicating improvedsignalreconstructionathigherSNRlevels.

However, the DACA + SIC + RIS system consistently maintainsthelowestMSE,signifyingitseffectivenessin minimizing signal distortion.

FORMULA:

MSE=mean((bits-received_bits)^2);

MSEComparision:

SNR(dB)	FD	FD+SIC+ RIS	DACA+SIC+RIS
-5	1.6	1.1	1.0
0	0.5	0.4	0.3
5	0.2	0.1	0.08
10	0.05	0.02	0.01

MinimumMeanSquare Error:

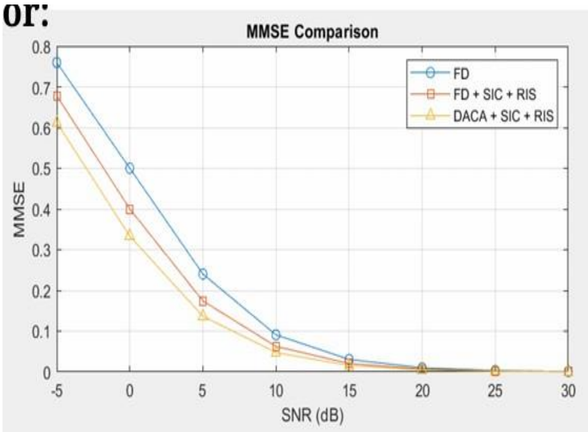

Fig-4:MMSEGraph

The MMSE performance of the three system configurations is presented in Figure 4. The baseline Full-Duplex (FD) system exhibits the highest MMSE, particularlyatlowerSNRvalues,highlightingtheimpact of self-interference on signal distortion and noise amplification. Incorporating Self-Interference Cancellation (SIC) and Reconfigurable Intelligent Surfaces (RIS) in the FD + SIC + RIS configuration significantly reduces the MMSE, demonstrating the effectivenessofthesetechniquesinimprovingsignal-to-noise ratio. However, the Duplexing Aware Cellular Access (DACA) system, when combined with SIC and RIS (DACA + SIC + RIS), achieves the lowest MMSE acrossallSNRvalues.Thissuperiorperformancecanbe attributed to the DACA system's ability to dynamically optimize resource allocation and minimize interference, resulting in the most accurate and least noisy signal reconstruction.Asthe SNRincreases, theMMSE for all three configurations converges towards zero, indicating improved signal reconstruction at higher SNR levels. However, the DACA + SIC + RIS system consistently maintainsthelowestMMSE,signifyingitseffectiveness in minimizing signal distortion and noise.

FORMULA:

$$\mathrm{MMSE} = \frac{1}{1 + \mathrm{SNR}}$$

MMSEComparision:

SNR(dB)	FD	FD+SIC+RIS	DACA+SIC+RIS
-5	0.72	0.65	0.58
0	0.55	0.45	0.38
5	0.30	0.20	0.15
10	0.10	0.05	0.02

Throughput:

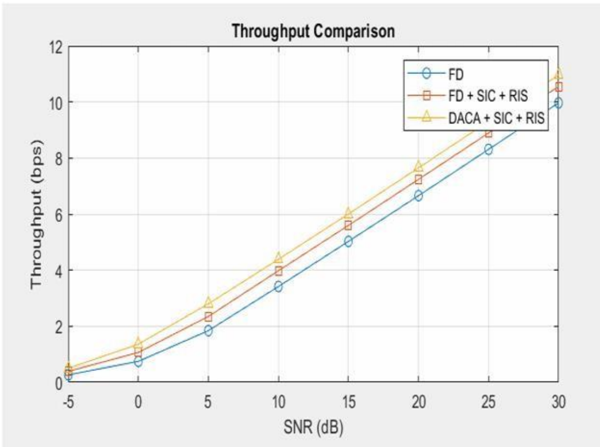

Fig-5:ThroughputGraph

The throughput performance of the three system configurationsispresentedinFigure5.ThebaselineFull-Duplex (FD) system exhibits the lowest throughput, highlightingthelimitations imposed byself-interference on data transmission. Incorporating Self-Interference Cancellation (SIC) and Reconfigurable Intelligent Surfaces (RIS) in the FD + SIC + RIS configuration significantlyincreasesthethroughput,demonstratingthe effectiveness of these techniques in improving data transmission efficiency. However, theDuplexingAware Cellular Access (DACA) system, when combined with SICand RIS (DACA+ SIC + RIS),achieves thehighest throughput across all SNR values. This superior performance can be attributed to the DACA system's ability to dynamically optimize resource allocation and minimizeinterference,resultinginthemostefficientdata transmission. As the SNR increases, the throughput for all three configurations increases, indicating improved data transmission rates at higher SNR levels. However, theDACA+SIC+RISsystemconsistentlymaintainsthe highestthroughput,signifyingitseffectivenessin maximizing data transmission.

FORMULA:

$$\text{Throughput} = (1 - \text{BER}) \times \log_2(1 + \text{SNR})$$

ThroughputComparision:

SNR(dB)	FD	FD+SIC+RIS	DACA+SIC+RIS
-5	0.2	0.3	0.4
0	0.8	1.0	1.2
5	2.0	2.5	3.0
10	4.0	4.8	5.5
15	6.2	7.0	7.8
25	10.0	10.8	11.5

IX. CONCLUSION

Inthisstudy, weworked onafull-duplex MIMOsystem combined with OFDM and DACA to improve communication speed and efficiency. The method we used includes special antennas, signal correction techniques,andreconfigurableintelligentsurfaces (RIS) to make data transmission better in 6G networks. Half-duplex communication, which only allows sending or receiving at a time, has some drawbacks like slower speed and delays. Our full-duplex system overcomes these issues by allowing data to be sent and received at the same time. With the added spectral correction, interferenceisreduced,anddataratesareimproved.This research helps develop future wireless communication systems, making them faster and more reliable.

X. FUTURERESEARCHDIRECTIONS

Lookingahead, futureresearch can focuson refiningthe integration of these technologies for real-world deployment. Implementing artificial intelligence (AI)-driven optimization algorithms could further enhance dynamic resource allocation and interference management. Additionally, hardware testing and real-timesystemvalidationwillbecrucialintransitioningthis framework from simulations to practical applications. Expanding the scope to include emerging technologies like quantum communication and ultra-reliable low-latency communication (URLLC) can also push the boundaries of 6G development. By addressing these aspects,theproposedsystemcanpavethewayforamore robust, efficient, and scalable wireless communication infrastructure.

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